FEMA

FEMA's Coastal Flood Hazard Analyses in the Atlantic Ocean and Gulf of Mexico

Probabilistic Flood Hazard Assessment – Panel 7

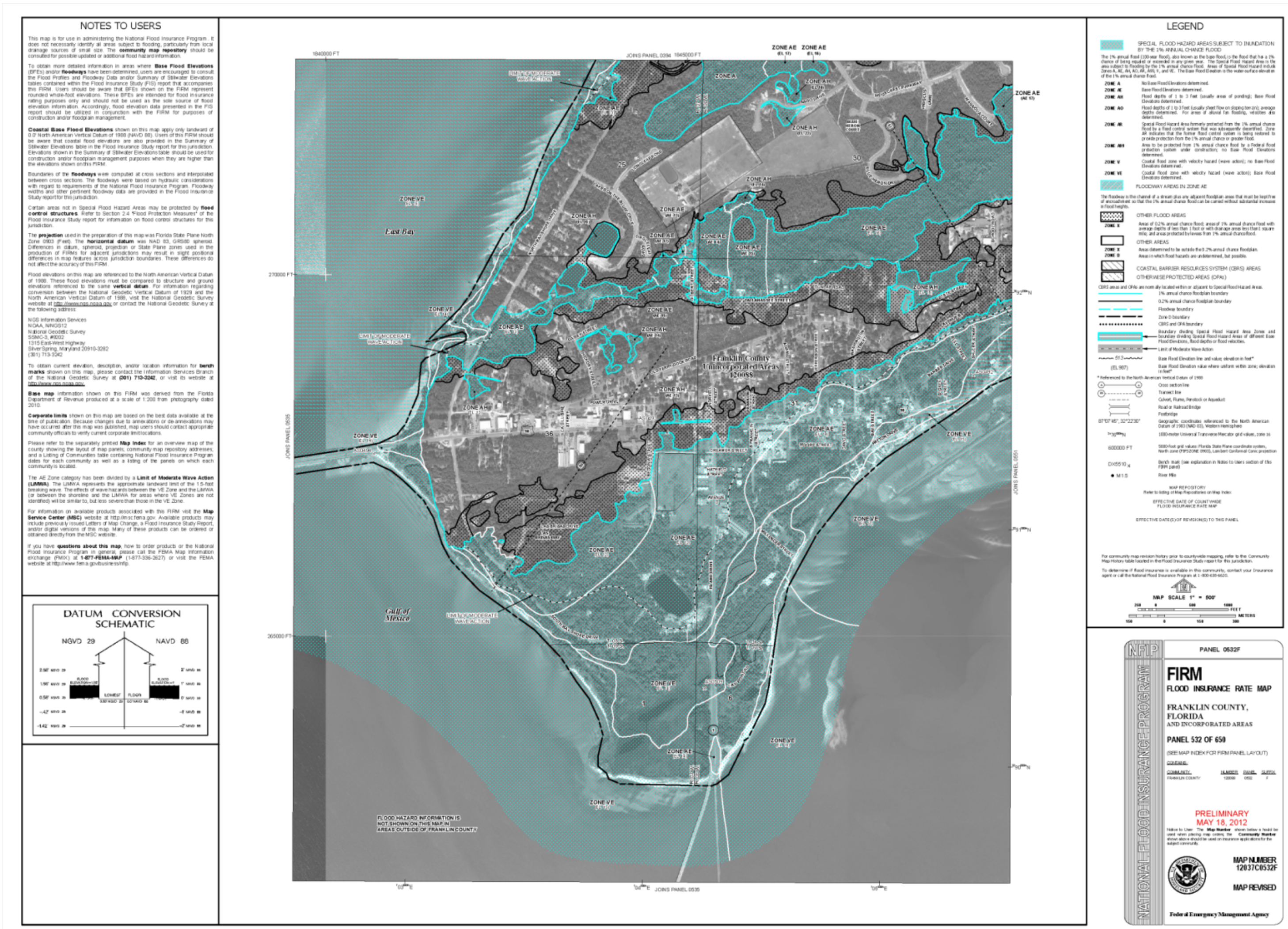
January 31, 2013

RiskMAP
Increasing Resilience Together

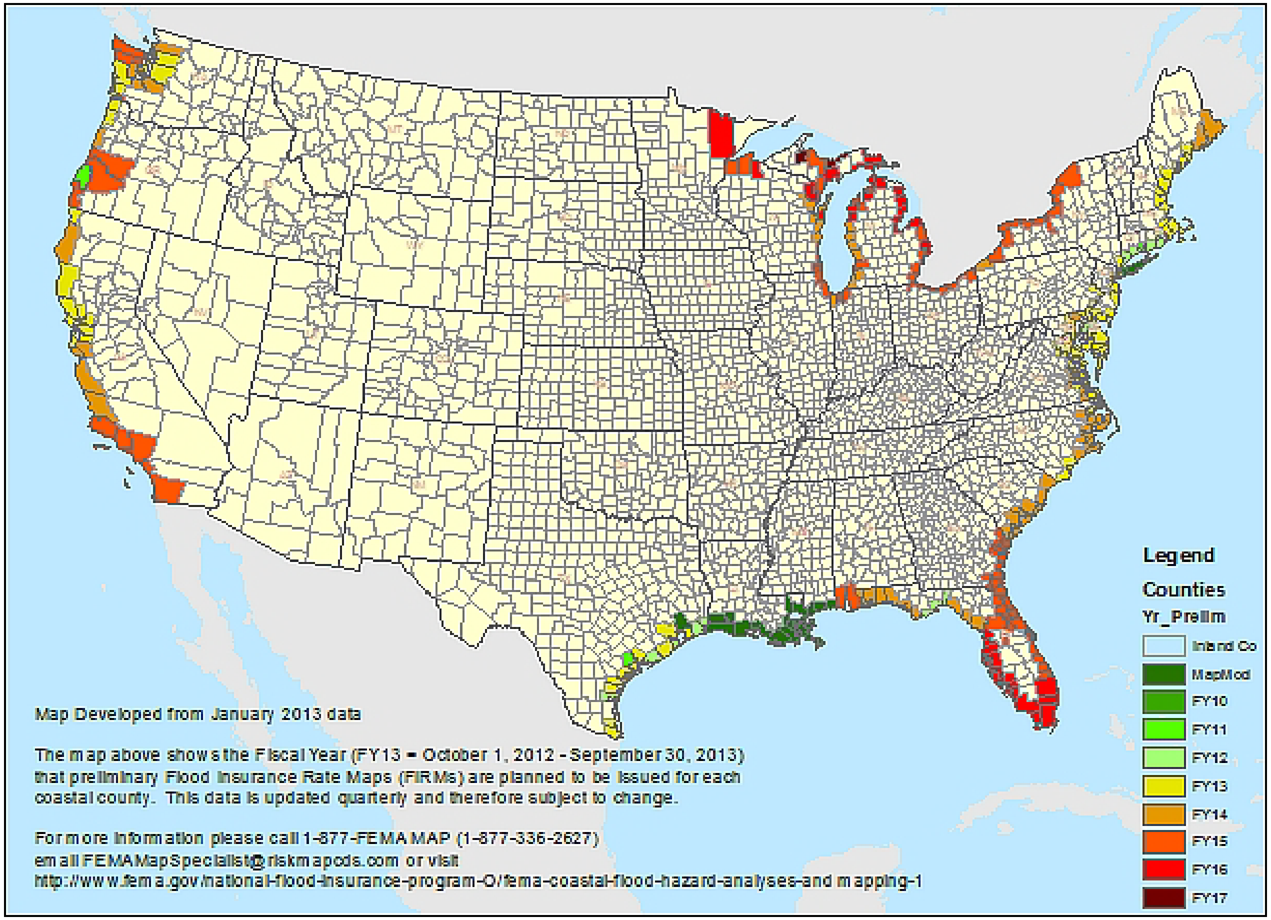
Agenda

- Introduction to FEMA's Mission & Coastal Flood Hazard Mapping
- JPM-OS for Storm Surge Modeling in the Atlantic Ocean & Gulf of Mexico
- Areas for Collaboration & Improvement

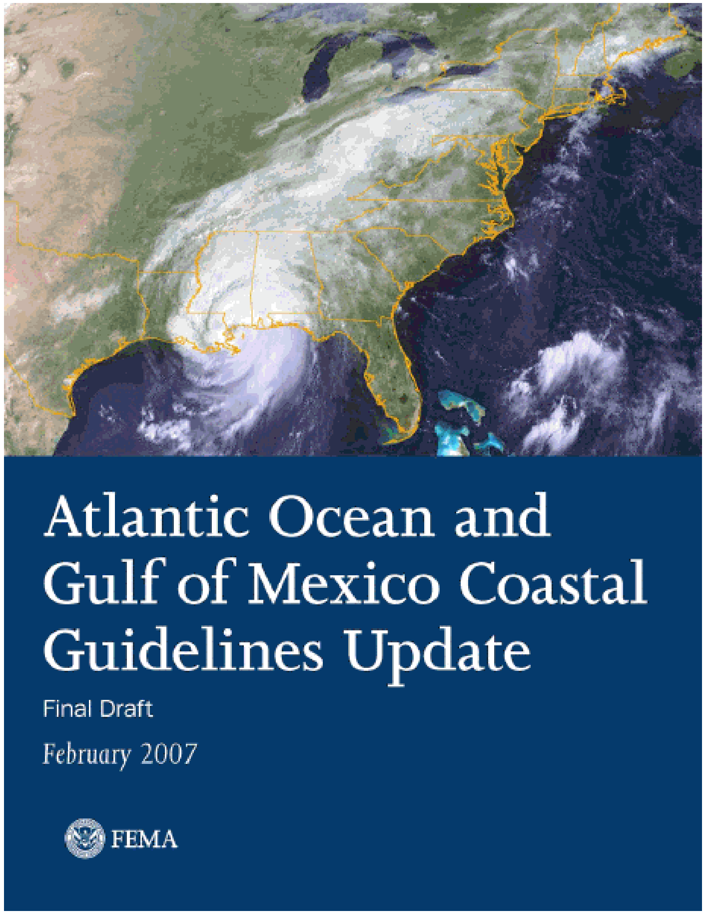
FEMA & Flood Hazard Mapping



FEMA & Flood Hazard Mapping



Atlantic Ocean & Gulf of Mexico

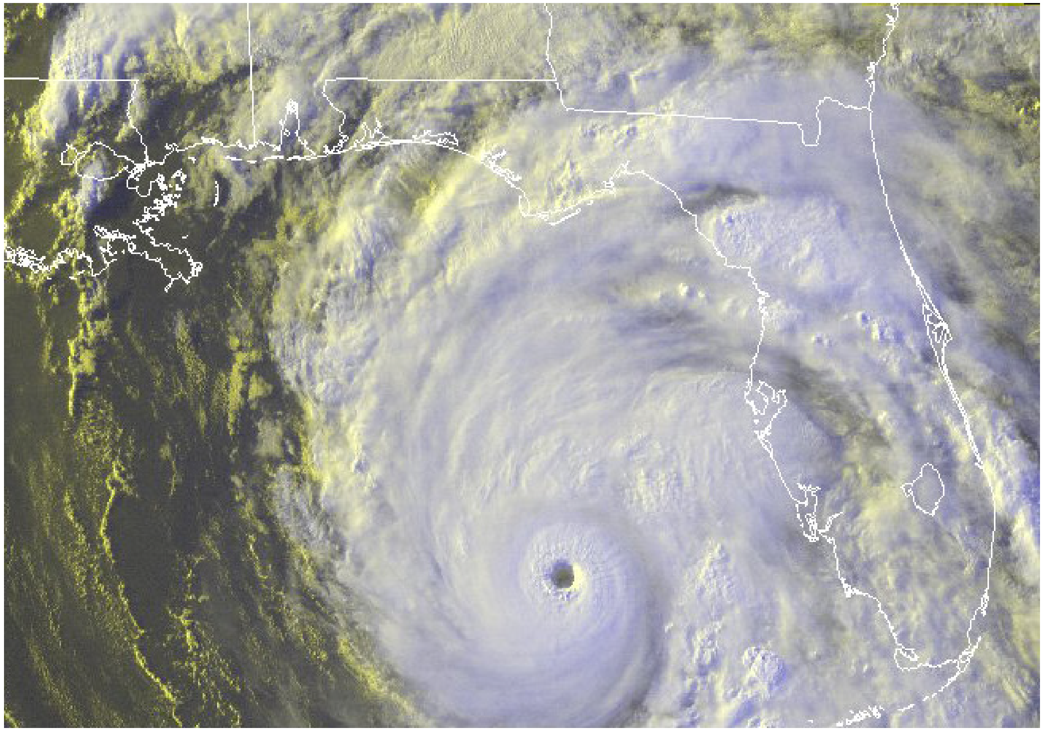


Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update

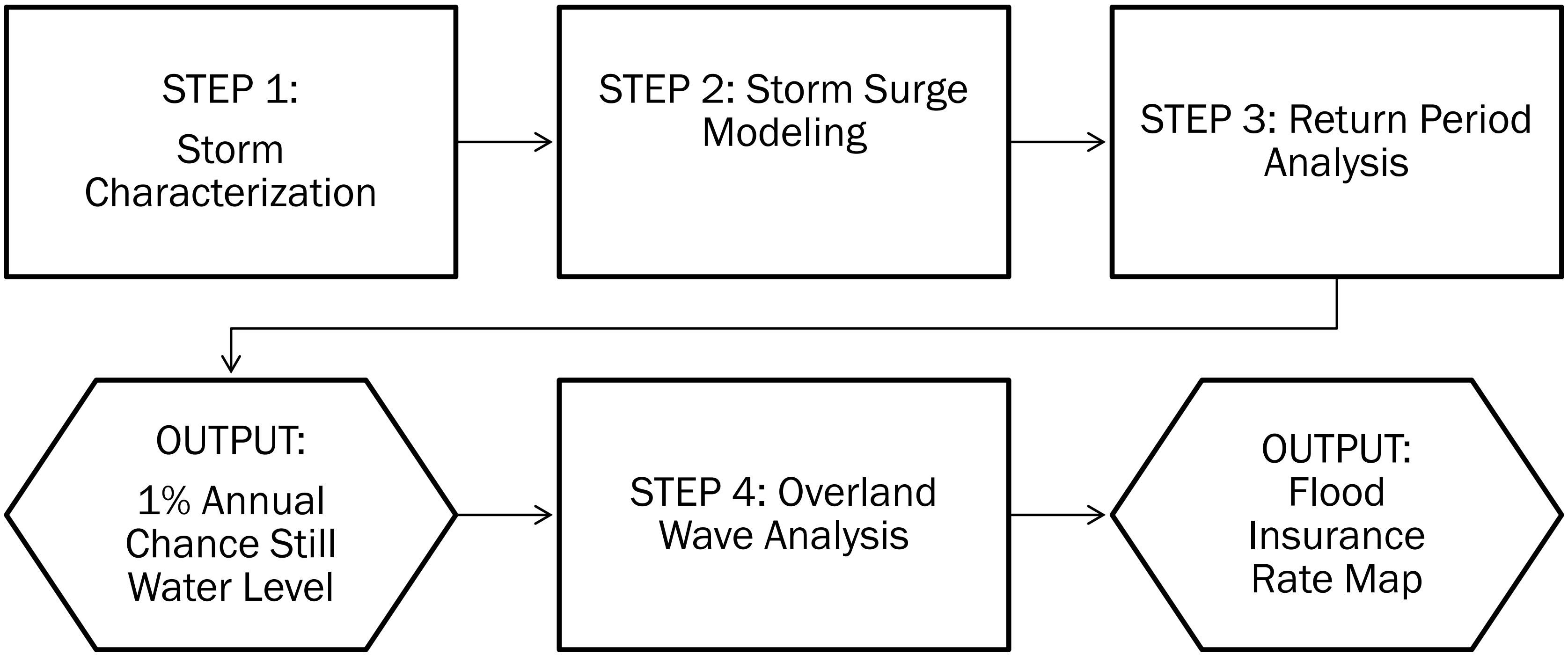
Final Draft

February 2007

FEMA



Numerical Modeling Framework

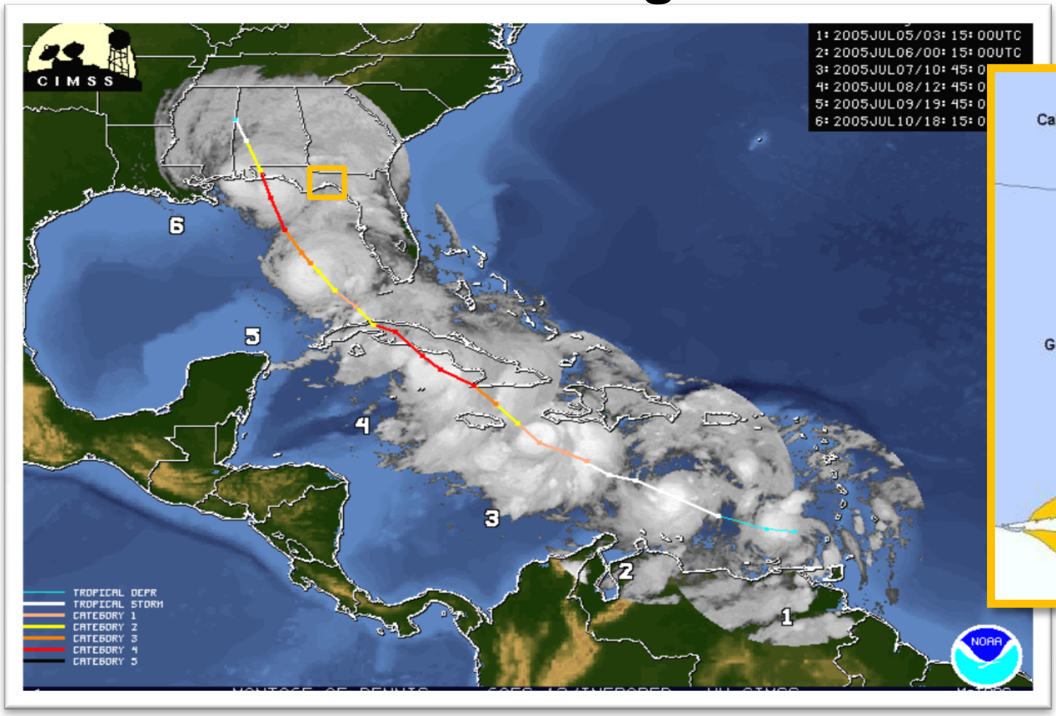


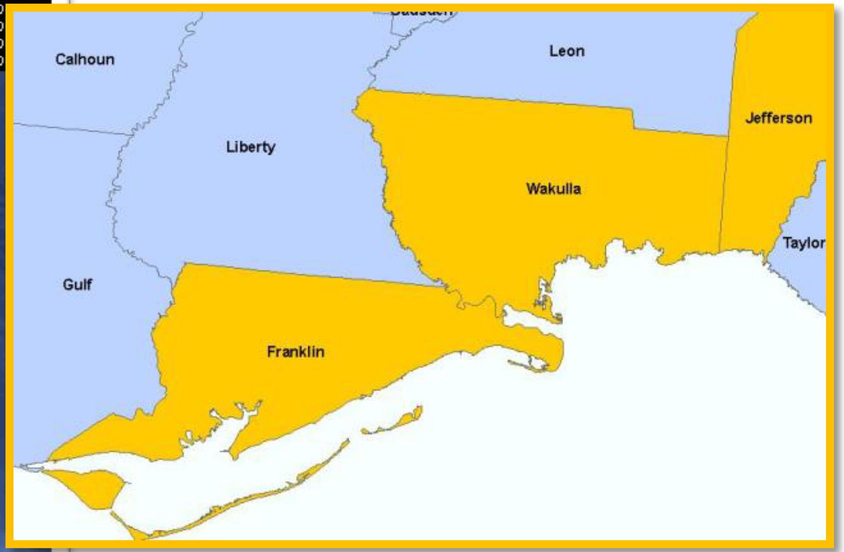
Step 1: Storm Forcing

A. Storm Rate and Storm Characterization

B. JPM-OS and Representative Synthetic Storms

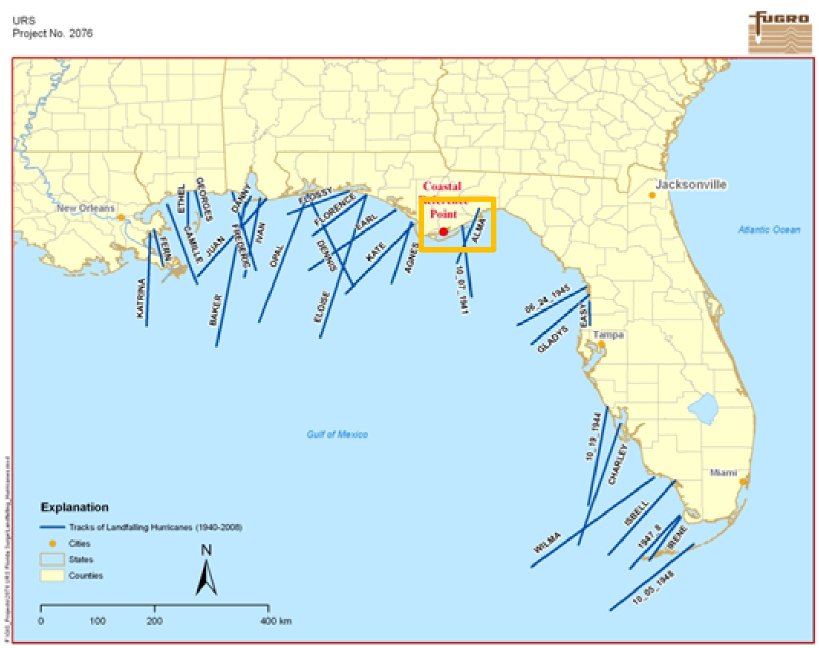
C. Validation of “OS” using SLOSH or a coarse ADCIRC mesh



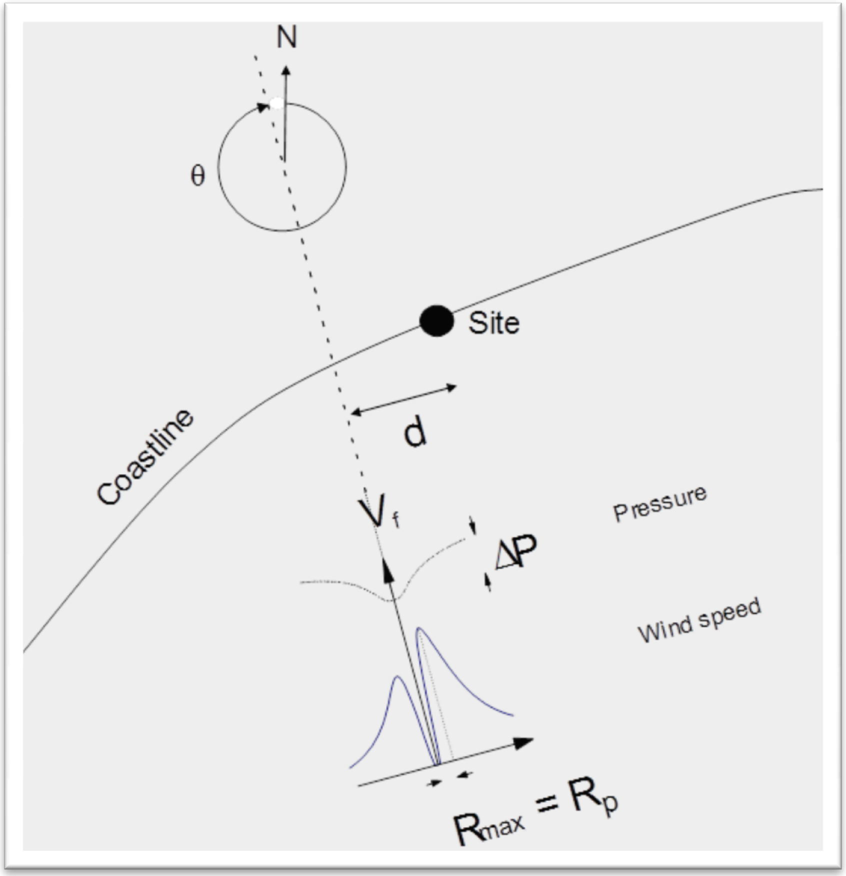


Step 1A: Storm Characterization

- storm occurrence rate λ
- pressure deficit ΔP
- radius of the exponential pressure profile R_{max}
- forward velocity V_f
- storm heading θ
- landfall location d

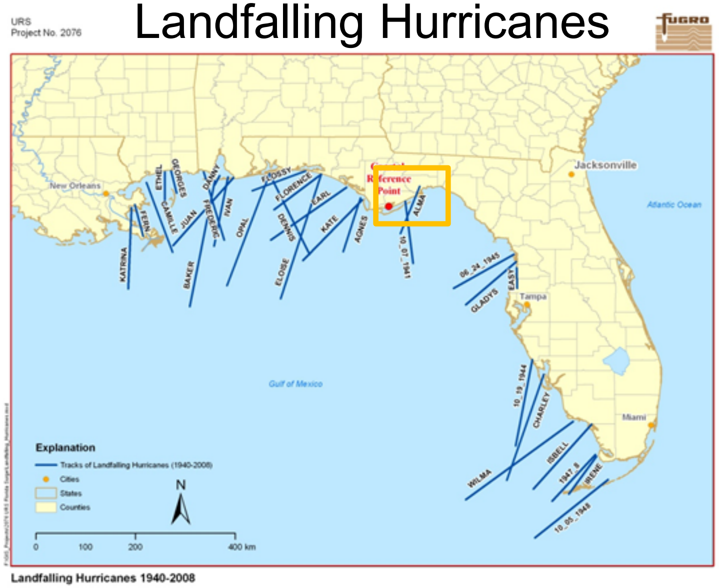


Landfalling Hurricanes 1940-2008

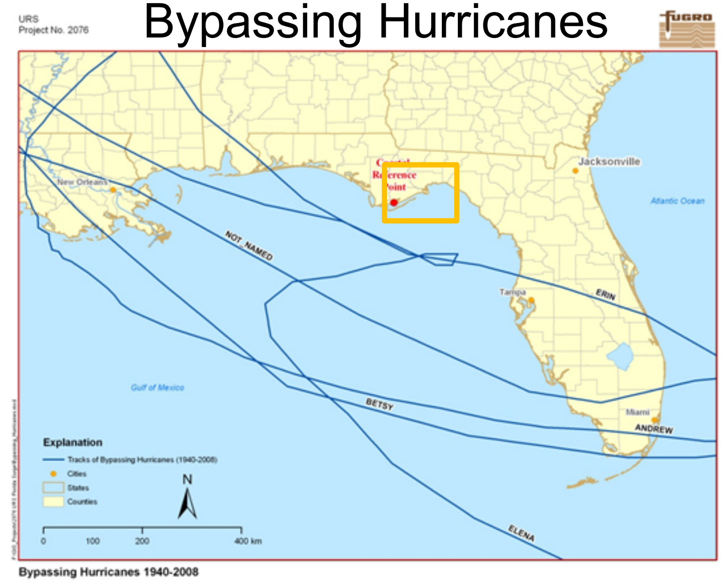


Step 1A: Establishing Storm Rate (storms/year/km)

Landfalling Hurricanes



Bypassing Hurricanes



$$\lambda = \frac{1}{T} \sum_{\substack{i \\ \text{(all storms)}}} k(d_i)$$

$$k(d_i) = \frac{1}{\sqrt{2\pi h_d}} \exp\left[-\frac{1}{2} \left(\frac{d_i}{h_d} \right)^2 \right]$$

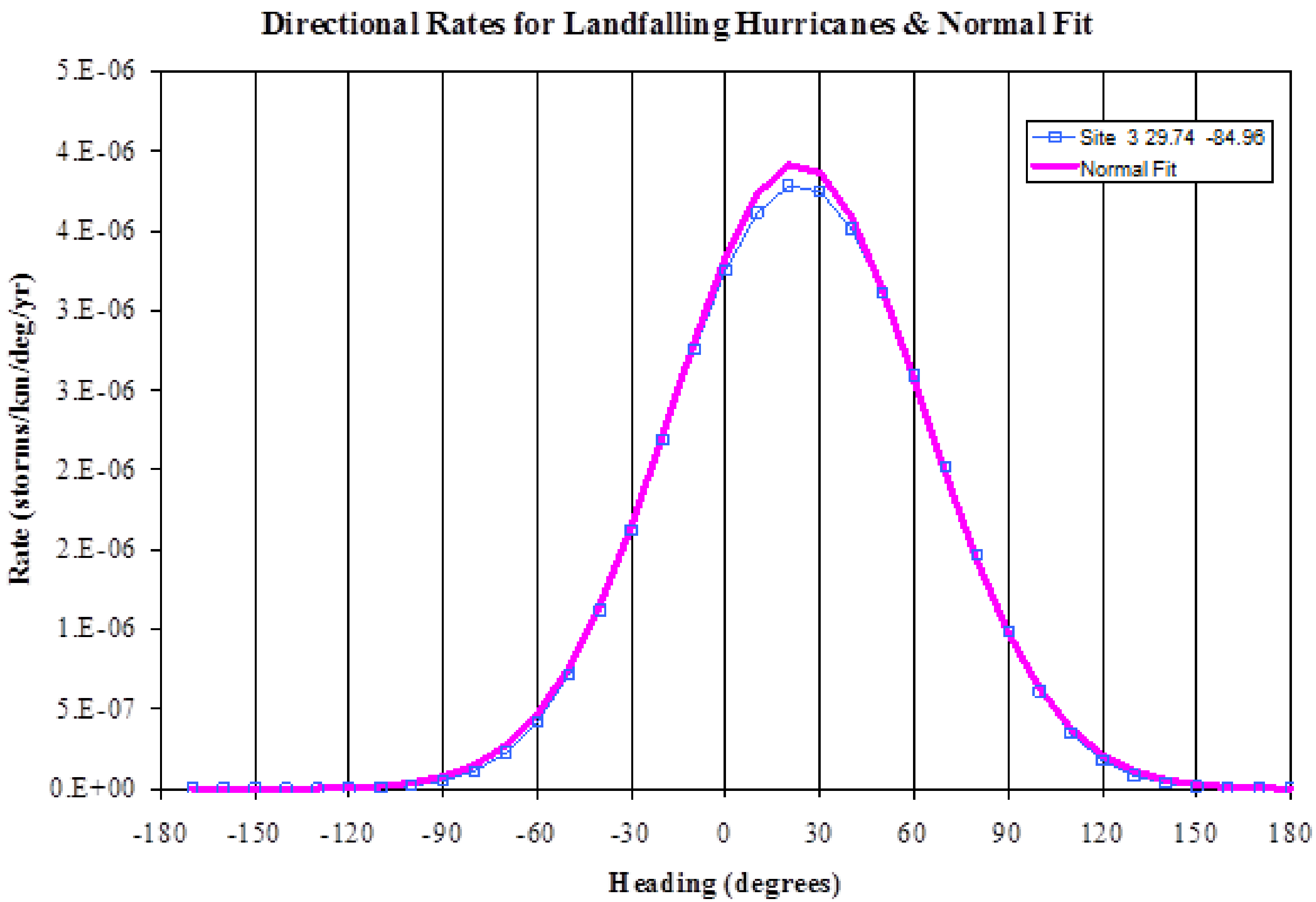
h_d ~ 200 km

$$\lambda(\theta) = \frac{1}{T} \sum_{\substack{i \\ \text{(all storms)}}} k(d_i) k(\theta_i - \theta)$$

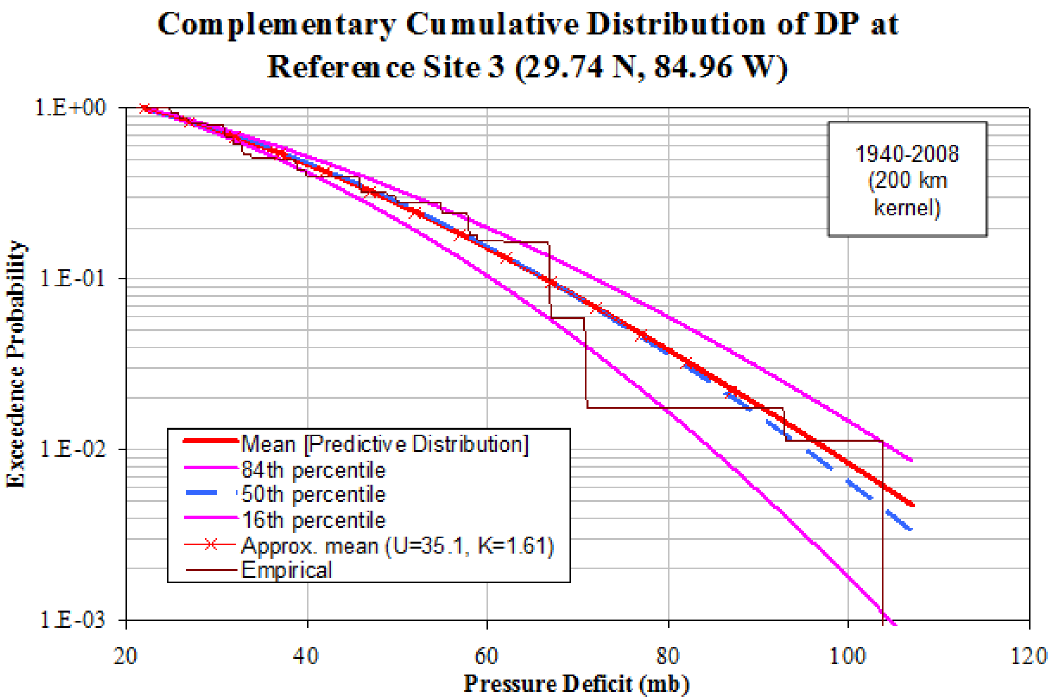
$$k(\theta_i - \theta) = \frac{1}{\sqrt{2\pi h_\theta}} \exp\left[-\frac{1}{2} \left(\frac{\theta_i - \theta}{h_\theta} \right)^2 \right]$$

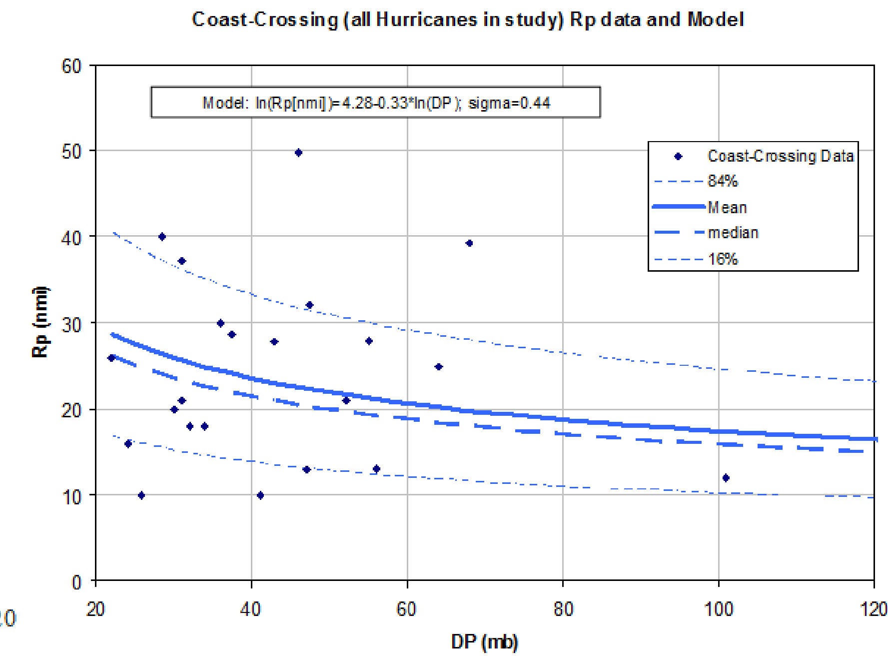
h_θ ~ 30°

Step 1A: Establishing Storm Heading



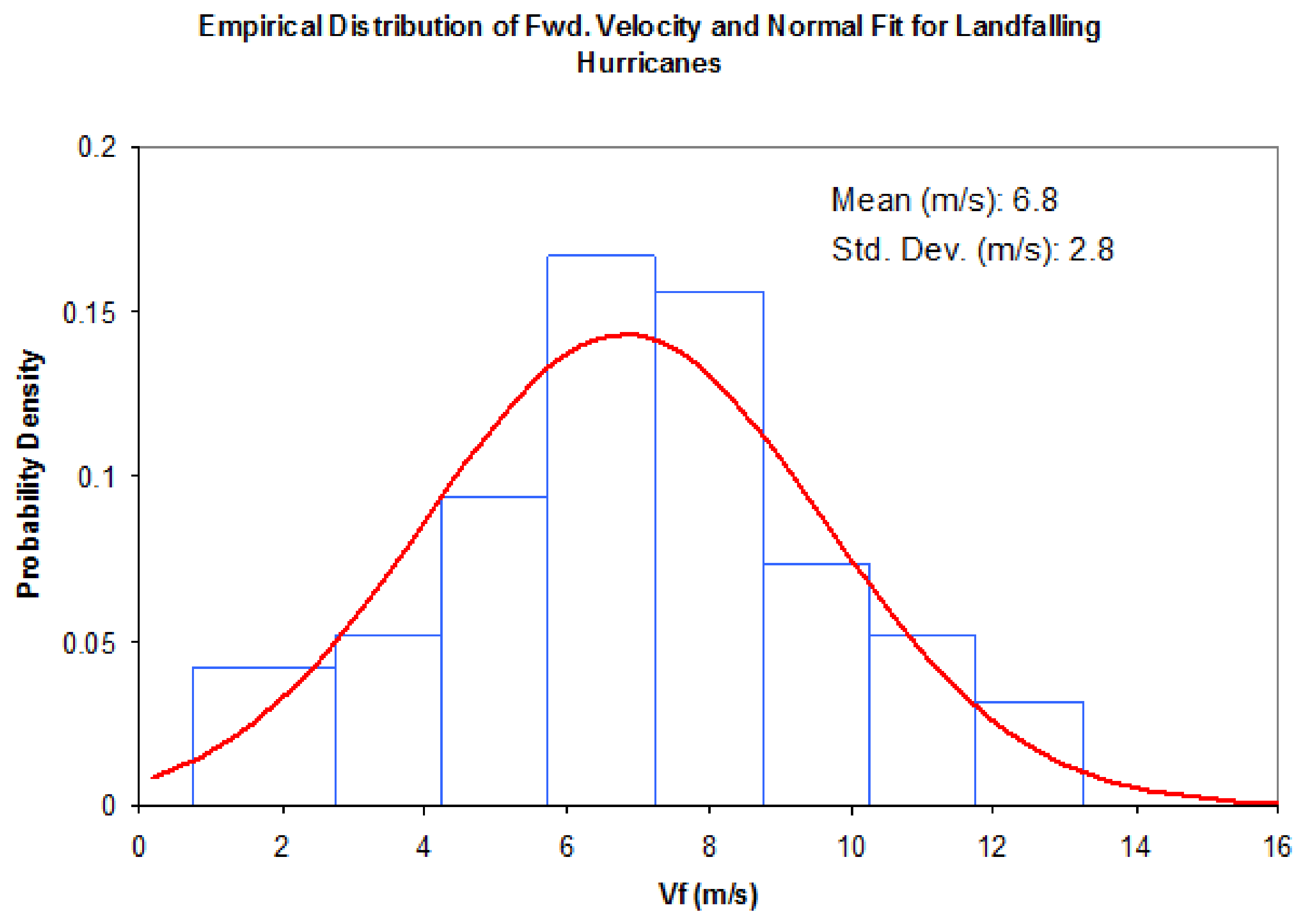
Step 1A: Characterization of Storm Parameters





$$P[\Delta P > x] = \exp[-(x/u)^k + (\Delta P_0/u)^k] \qquad x > \Delta P_0$$

Step 1A: Characterization of Storm Parameters



Step 1B: Storm Tracks

1. **The geometry of the tracks is defined based on:**
   a) Similar work performed by USACE for probabilistic storm surge studies for MS & LA
   b) Historical tracks for the regions (as performed in NC, SC)

2. **Storm parameters, R_p, ΔP, and B are specified for each point along the track, based on the specified conditions at landfall from the probabilistic analysis.**

Step 1B: JPM Development

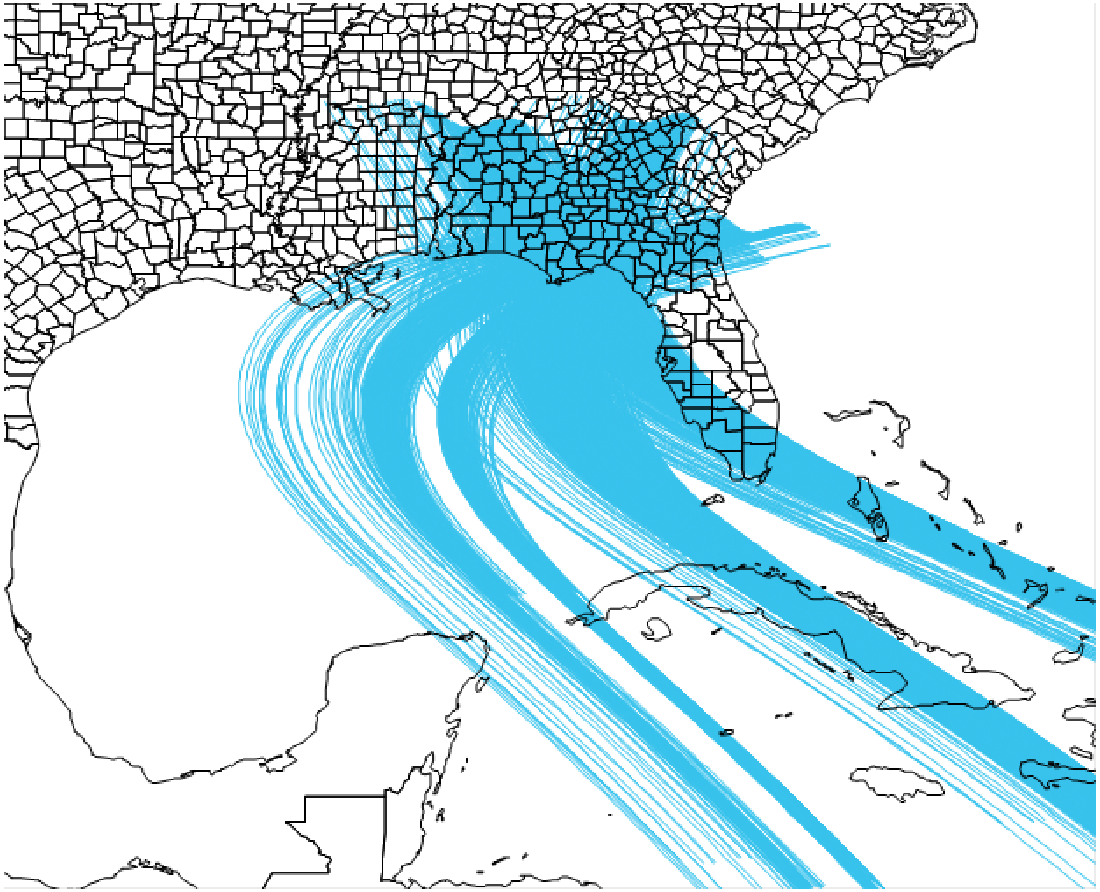
$$P[\eta_{\max(1\,yr)} > \eta] = \lambda \int \ldots \int_{\underline{x}} f_{\underline{X}}(\underline{x}) P[\eta_m(\underline{x}) + \varepsilon > \eta]\, d\underline{x} \approx \sum_{i=1}^{n} \lambda_i P[\eta_m(\underline{x}_i) + \varepsilon > \eta]$$

- λ: Annual rate (storms/km/yr)
- $f_{\underline{X}}(\underline{x})$: Joint Probability Distribution of Storm Characteristics
- $P[\eta_m(\underline{x}) + \varepsilon > \eta]$: Storm generated surge
- λ_i: Annual rate for synthetic storm *i*
- $\eta_m(\underline{x}_i)$: Numerical model estimate of storm surge elevation

$$\underline{x}_i = (\Delta P_i, Rp_i, V_{f,i,} \text{landfall location}_i, \theta_i)$$

1. Discretize ΔP into multiple broad slices
2. Within each slice, discretize the joint probability distribution of ΔP , R_p, V_f and θ using Bayesian Quadrature.
3. Discretize landfall location by offsetting each synthetic storm by R_p, as measured perpendicular to the track.
4. Compute the probability, pi, assigned to each synthetic storm as the product of the probabilities from the first 3 steps.

Step 1B: Reference Synthetic Storms



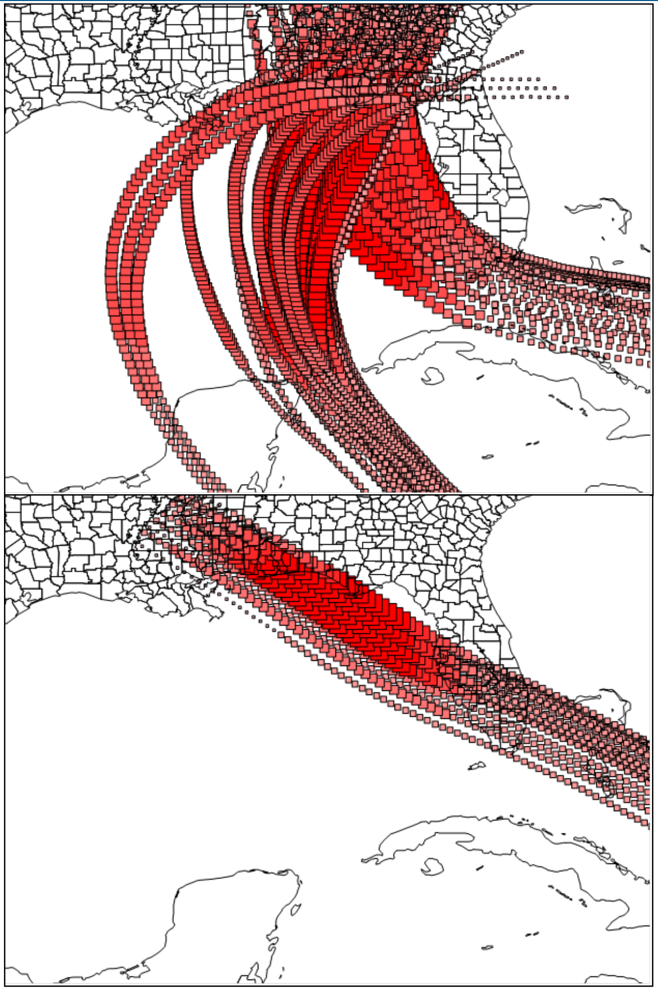
Step 1B: JPM-OS Development

Example: JPM-OS representation of joint probability distribution of storm characteristics for landfalling hurricanes

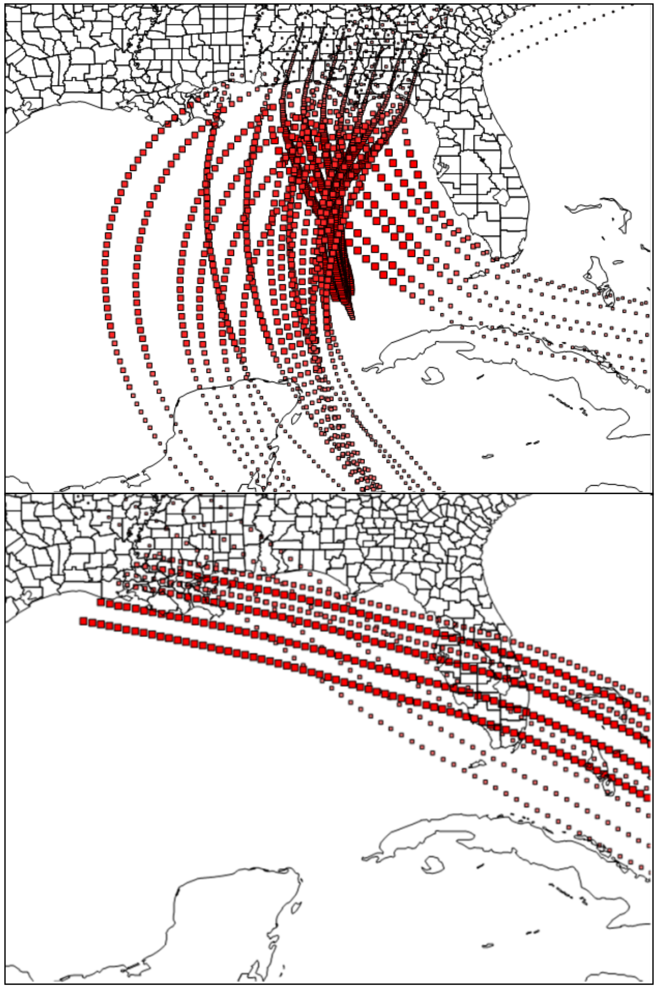
Probability	ΔP (mb)	Rp (nmi)	Vf (m/s)	Theta (deg)
0.248	26.0	36.6	6.8	23.0
0.209	35.3	16.3	6.8	23.0
0.139	42.0	33.2	6.8	23.0
0.094	46.8	14.9	6.8	23.0
0.049	48.9	10.3	5.9	26.6
0.033	56.5	36.4	4.2	61.1
0.057	57.8	19.2	3.9	-12.7
0.046	58.8	17.5	7.1	86.8
0.035	61.7	14.4	11.3	-8.0
0.030	63.4	34.0	9.5	-10.9
0.026	80.4	9.5	5.5	23.7
0.034	87.0	20.2	6.8	28.3

Step 1B: JPM-OS Synthetic Storms

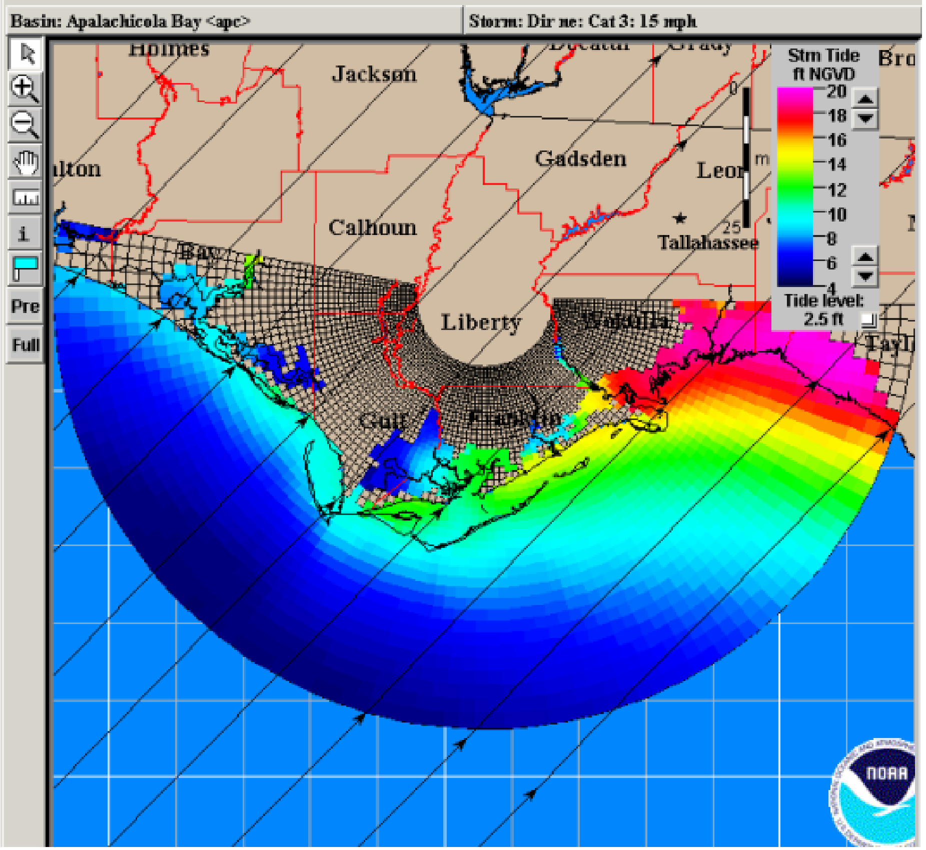
Hurricanes – Landfalling and Bypassing

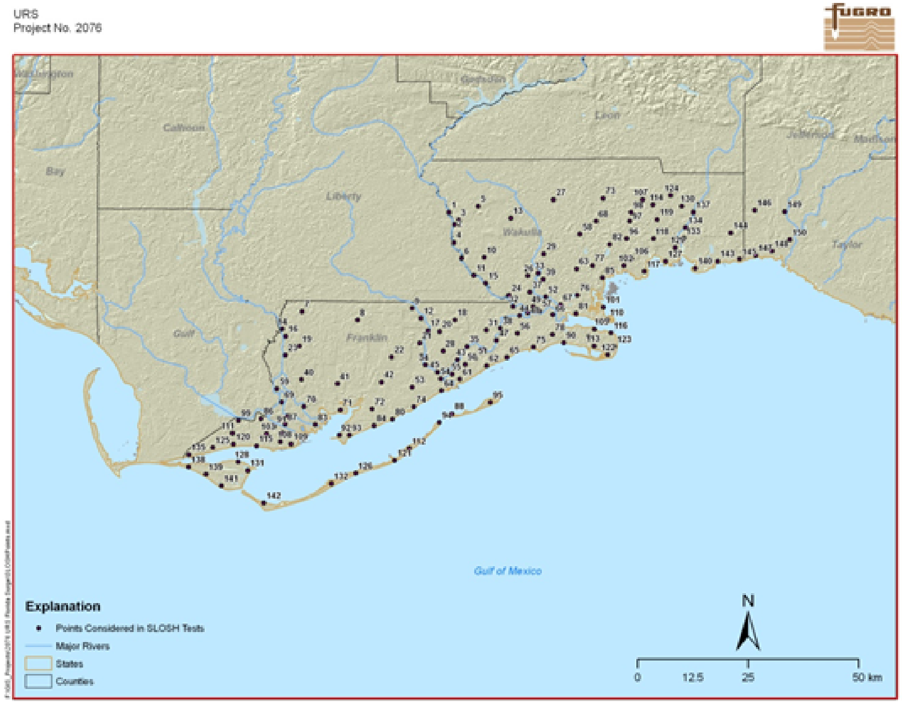


Tropical Storms – Landfalling and Bypassing



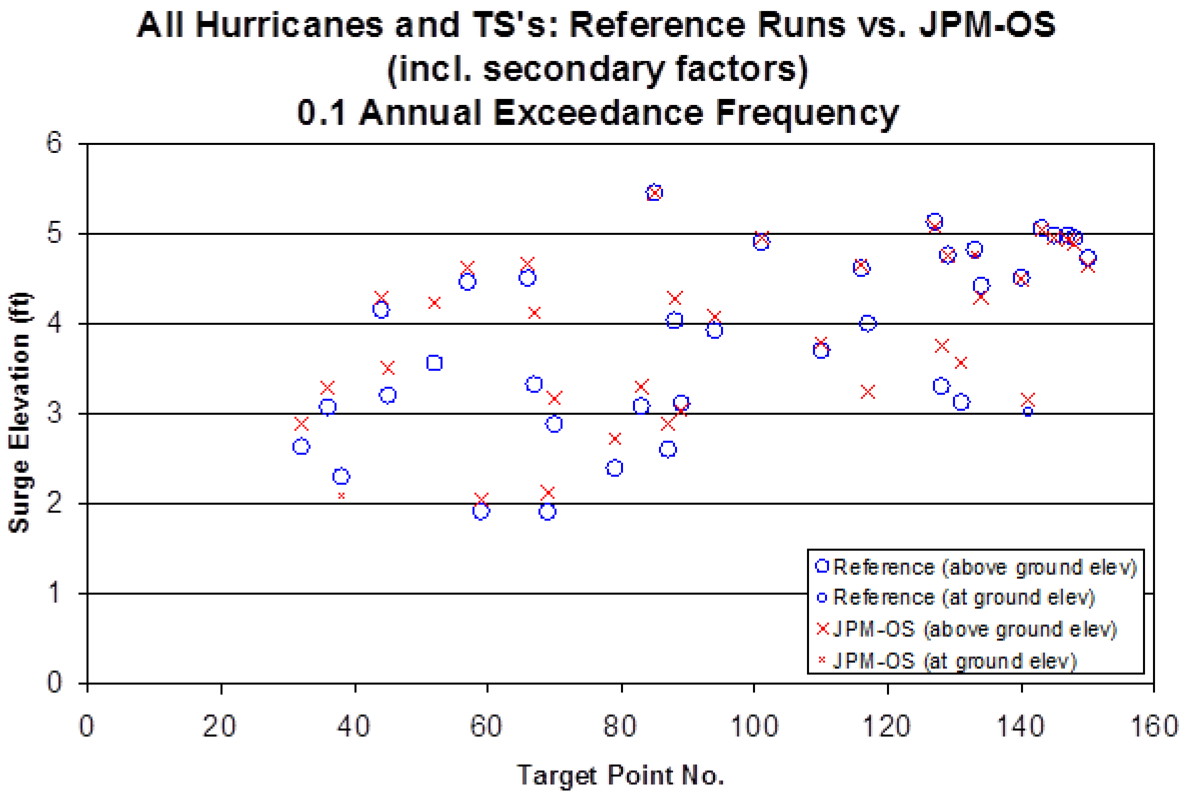
Step 1C: Comparing Reference and JPM-OS Synthetic Storm Suites



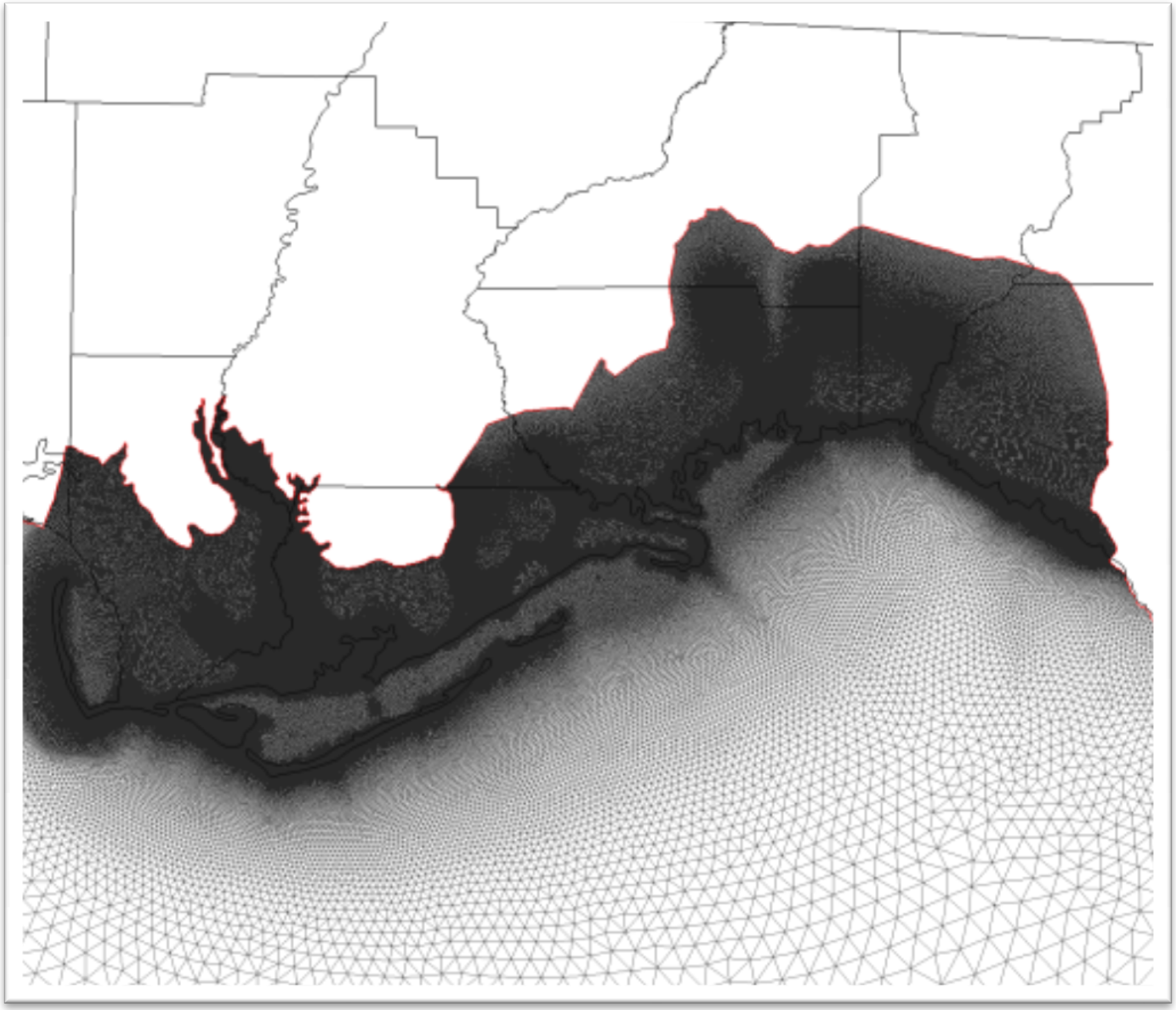


Points Considered in SLOSH Tests

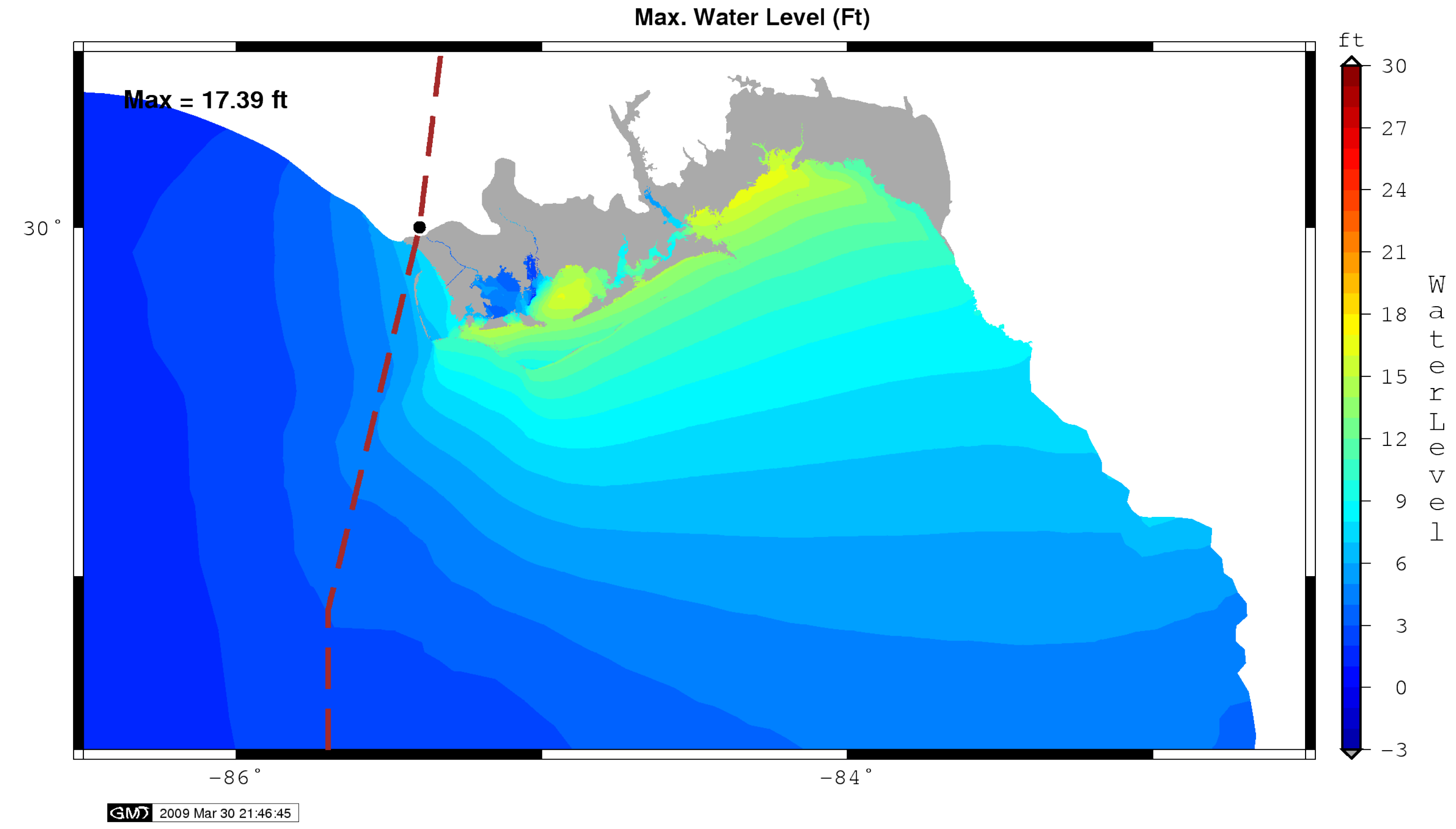
Step 1C: Comparing JPM and JPM-OS



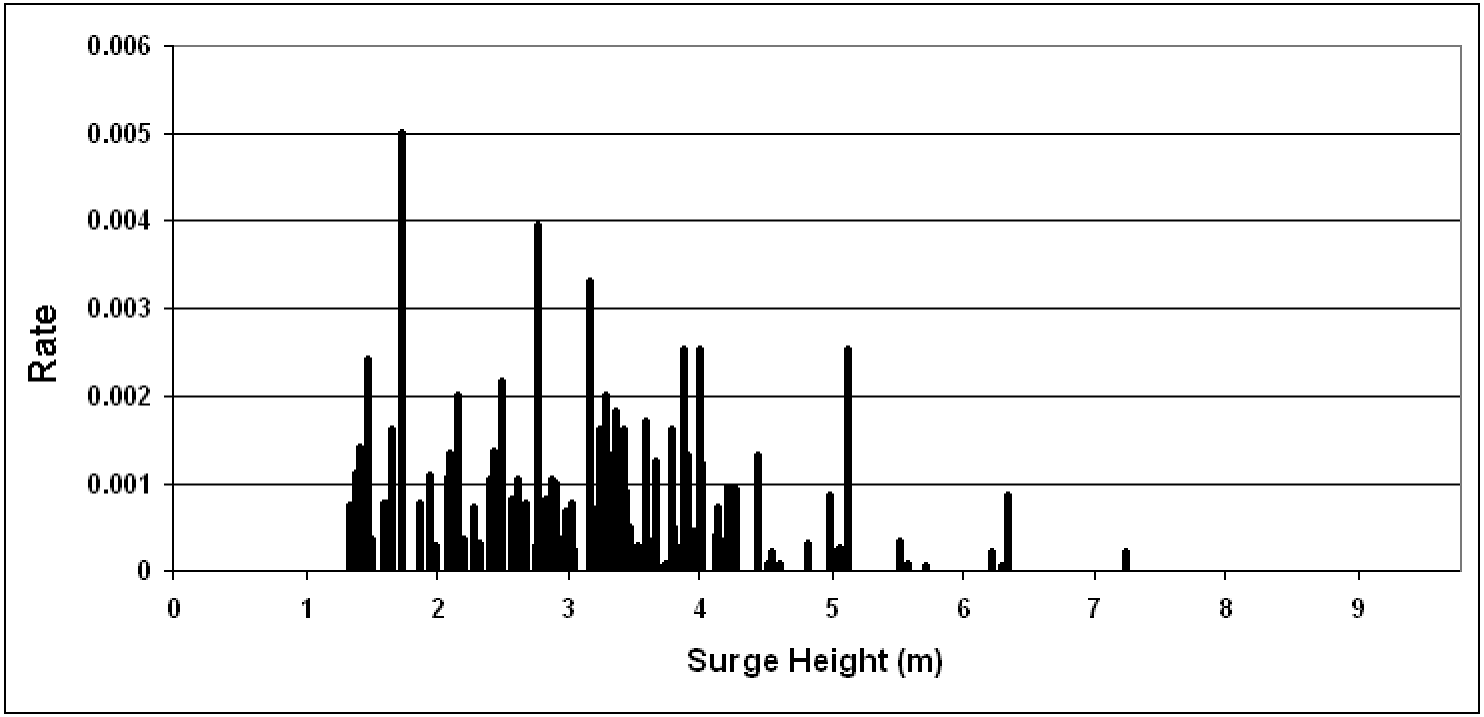
Step 2: Hydrodynamic & Wave Modeling



Step 2: Single Storm SWL Result

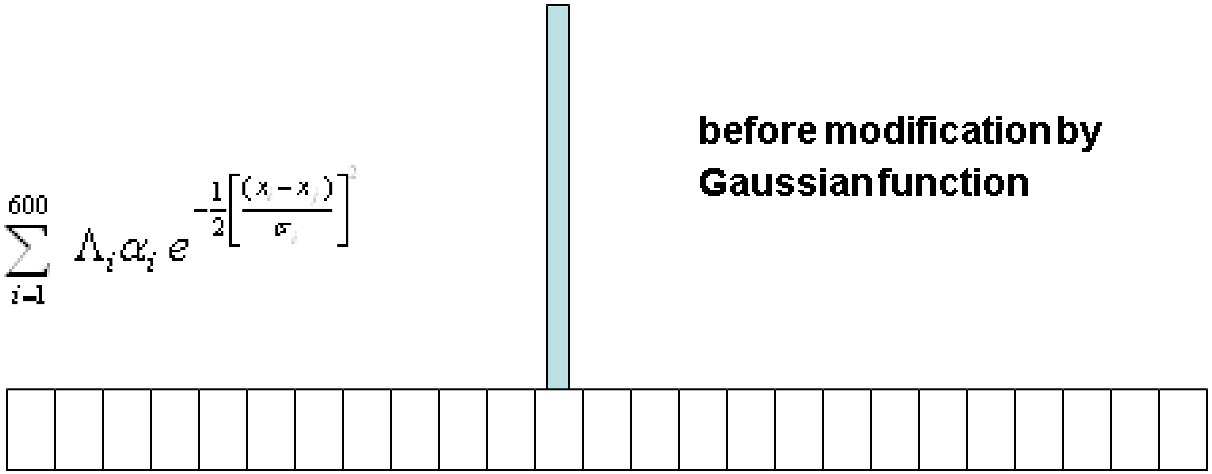


Step 3: JPM-OS SWL Results



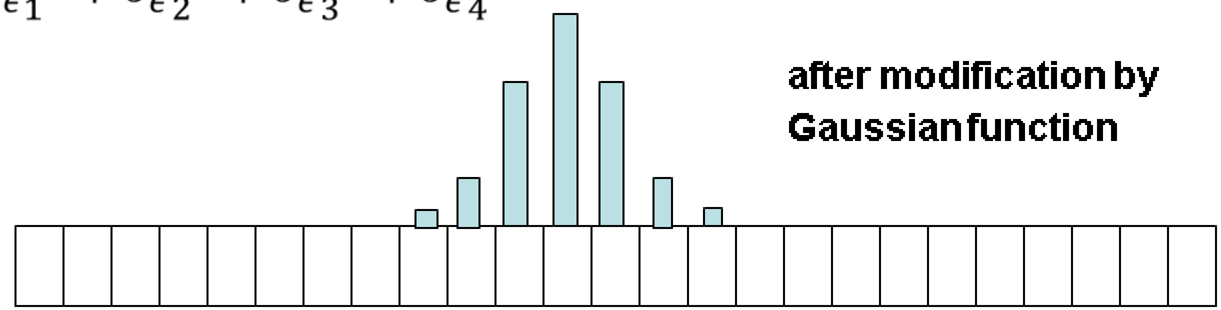
Step 3: Accounting for Uncertainty

$$\Lambda_j^{new} = \sum_{i=1}^{600} \Lambda_i \alpha_i \, e^{-\frac{1}{2}\left[\frac{(x_i - x_j)}{\sigma_i}\right]^2}$$



before modification by Gaussian function

$$\sigma = \sqrt{{\sigma_{\epsilon}}_1^{\,2} + {\sigma_{\epsilon}}_2^{\,2} + {\sigma_{\epsilon}}_3^{\,2} + {\sigma_{\epsilon}}_4^{\,2}}$$



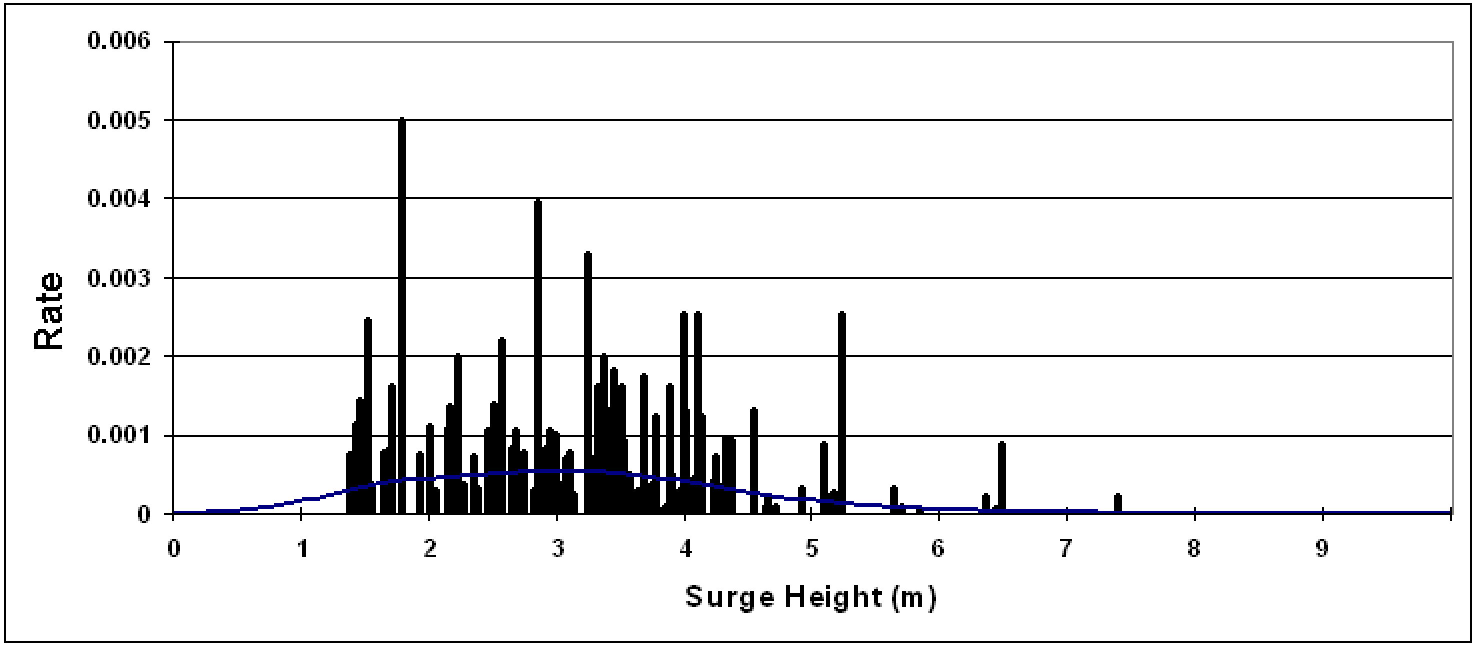
after modification by Gaussian function

Step 3: Accounting for Uncertainty

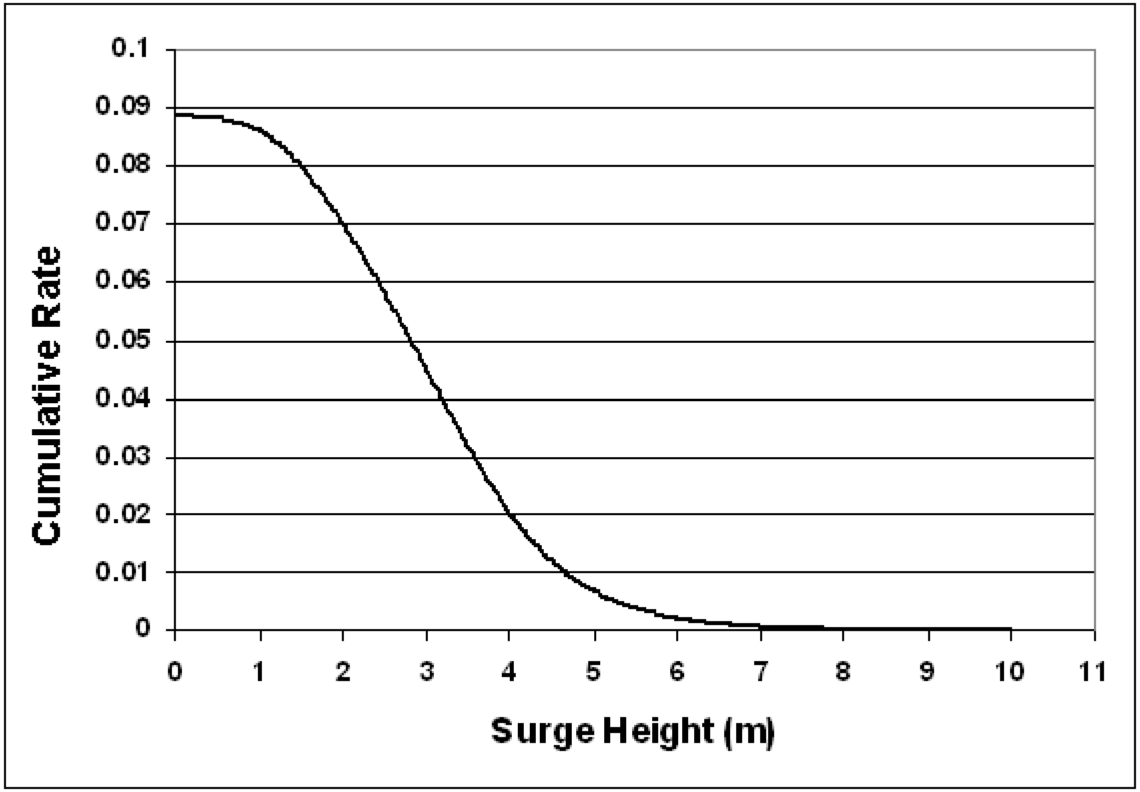
- ε_1 This is the contribution from the astronomical tide. A storm can make landfall at any phase of the tide. This epsilon term is used to represent the effect of random phasing of the maximum storm surge and the astronomical tide.
- ε_2 This epsilon term represents the changes in surge heights due to unaccounted variability in the value of Holland B. This parameter is used in the PBL numerical model of hurricane winds and pressures to account for the radial gradients.
- ε_3 This epsilon term represents the departures between modeled and measured surge levels and is used to express variations in the surge heights due to lack of accuracy in the modeling results.
- ε_4 This epsilon term represents the uncertainty associated with using idealized wind fields for the surge simulations, instead of the "best" or measured wind fields.

Step 3: Accounting for Uncertainty

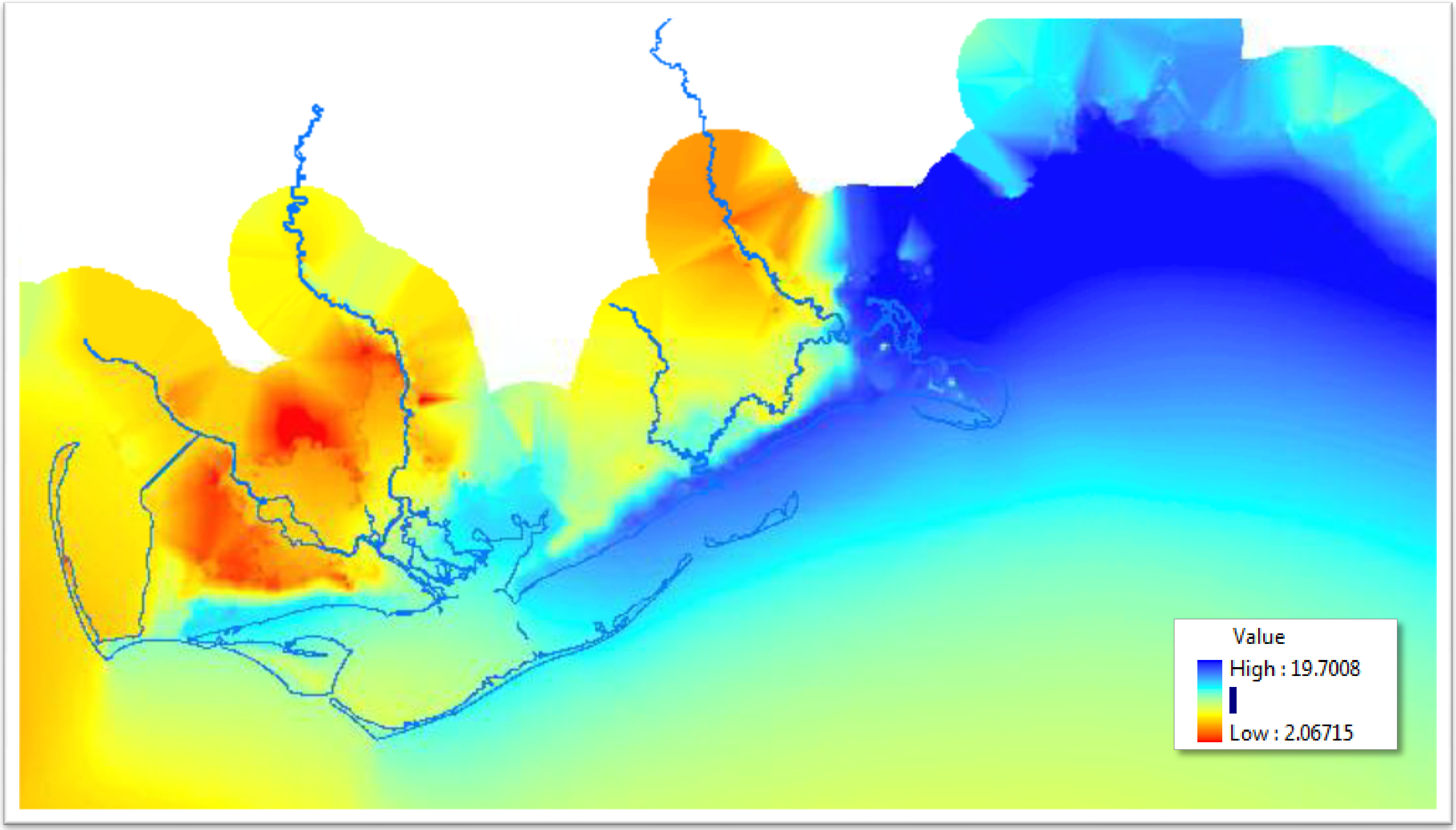
- The effect of the inclusion of the uncertainty term is shown by the blue line in the figure below



Step 3: Final SWL Results



Step 3: Final SWL Results



What can we share with Partners?

- **2D storm surge modeling**
  - Seamless Digital Elevation Model
  - Model mesh
  - Model choice
  - Overland wave modeling
- **Storm characterization & tropical system behavior**
  - Progress in understanding
  - Knowledge transfer needed
  - Area for plentiful future research
- **Treatment of Uncertainty**

Questions?

Thank you to Chris Reed (URS), Alan Niedoroda (URS), Chris Jones, Mark Osler (Baker), Darryl Hatheway (AECOM) & Cheryl Johnson (Accenture) for their shared expertise in this presentation.

Thank you to all FEMA mapping partners, who are the reason this substantial program has been so successful.

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